Thesis Topic: Beam Optics of Integrable Optics Test Accelerator and Implications for Advanced Accelerator R&D Experiments

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The only machine with sufficient energy resolution to directly measure the predicted 4 MeV width of the 126 GeV standard-model Higgs Boson is a muon collider tuned to the s-channel Higgs resonance. This $\mu^+\mu^-$ Higgs factory will need a six-dimensional (6D) cooling channel in order to achieve the required energy spread, something that will be challenging with the current methods of cooling. Optical stochastic cooling (OSC) is a proposed technique that looks promising for cooling beams in a proton collider and may be used for the LHC luminosity upgrade. If this benchmark is met, it may be plausible to extend such a technique to cool muons in a $\mu^+\mu^-$ Higgs factory. OSC will be demonstrated at the Integrable Optics Test Accelerator (IOTA) ring currently under development at Fermilab as a part of the Laboratory's Advanced Accelerator R&D Program (AARD). IOTA will be the backbone of a number of proof-of-principle beam physics experiments, which will also include but will not be limited to the nonlinear integrable optics test and the development of space charge compensation for high intensity charged particle beams.

A conventional wave-guide based stochastic cooling system has a bandwidth limited to about 10 GHz. An OSC channel can allow for an increase of more than three orders of magnitude in bandwidth to allow for faster and more comprehensive cooling. The OSC channel includes two undulators, an amplifier, and a bypass. The upstream undulator acts as a pickup whereby the particle bunch radiates an EM wave that gets propagated through an optical amplifier to the downstream undulator. Meanwhile, the bunch travels through a bypass to the second undulator, where it is kicked by its own amplified radiation. The light packet will be delayed by few a mm in the optical amplifier. To interact with its radiation a particle has to be delayed by the same amount. This is performed by beam lengthening in the bypass. Thus the bunch arrives at the second undulator simultaneously with its amplified radiation. Minor adjustments in bypass length allow one to adjust the relative phase of the wave so that there is no longitudinal kick on the reference particle. By adjusting the undulator-to-undulator partial slip factor and dispersions in both undulators longitudinal as well as transverse cooling can be achieved.

For system stability in the OSC channel, particles must be allowed to mix in order to mitigate incoherent heating. This is achieved in the particle travel through the rest of the ring (from the second undulator to the first.) However, there must be no particle mixing in the bypass (from the first undulator to the second) as this would affect the synchronicity between the bunch and its radiation. Only coherent components of the kicks are responsible for damping the beam. To prevent a slowdown of the longitudinal and transverse damping rates, the ring optics and dispersion must be tightly controlled including the bypass optics.

To accommodate the different needs of a broad spectrum of experiments at IOTA, the ring optics must be designed with significant flexibility in mind, but without compromising cost efficiency. The additional complication of the project is in the challenging requirements on the ring optics control reaching or exceeding the present state of the art. The goal of the thesis would be to develop a complete self-consistent design of the IOTA ring optics meeting the demands of all planned AARD experiments. Of particular interest are precise lattice control for the nonlinear integrable optics experiment and the transverse-to-longitudinal coupling and phase stability for optical stochastic cooling. A possible experimental part could be participation in, or oversight over, the magnetic measurements of the ring dipole magnets or possibly the special nonlinear magnets for the integrable optics experiment.

Preliminary plan and list of topics:

- Refresh the basics of linear beam optics in circular machines, basic properties of synchrotron radiation (essential for OSC)
- Learn the use of lattice design codes - MAD-X and OptiM - using a sample lattice
- Optimize the IOTA lattice design in 4D for the various experiments
- Optimize in 6D
- Learn about beam-based measurement techniques and study their potential at IOTA
- Iterate, if necessary, after cross-checking power supply requirements, engineering, vacuum, instrumentation, etc.
- Create and support a wiki-type resource for the project